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Framework development for LES numerical investigation of the in-cylinder phenomena inside DISI engines

Andrea Pati[1] and Christian Hasse[1]

[1] *Technical University of Darmstadt, Department of Mechanical Engineering, Simulation of reactive Thermo-Fluid Systems, Otto-Berndt-Straße 2, 64287 Darmstadt, Germany*

Internal combustion engines (ICEs) are an essential and common power source for personal and goods mobility. Despite their improvement over the last decades, they are still responsible for a relevant fraction of greenhouse gas and pollutant emission. Therefore, their optimization to enhance efficiency and minimize emission is crucial. In this context, numerical investigation methodologies can flank the experimental investigations due to the possibility of analyzing many aspects of the engine that can be prohibitive to measure.

This thesis develops a numerical method for engine simulation, striving towards accuracy, flexibility, stability, and computational efficiency. All of them are necessary for proficiency in the multidisciplinary numerical study of the engine both in the academic and industrial environment. This framework is used to perform a series of investigations on the phenomena preceding the combustion phase in a research engine, the Darmstadt optically-accessible engine.

Here, a new mesh motion methodology suitable for the DISI engine with complex geometry is developed. These methodologies are designed to achieve maximum accuracy for both RANS and LES simulations with minimum effort. Moreover, methodologies for multi-cycle simulation pre-processing and results analysis are derived. The strategy is fully validated by simulating a full-cycle of the Darmstadt engine in motored condition, at different operating conditions, using a RANS approach.

A new breakup model is proposed, specifically for predicting the evolution of the spray during the intake phase (early injection). Moreover, the newly developed model reduces the parameter adjustment, increasing the simulation reliability. A novel spray post-processing methodology is applied to compare the simulation with Mie scattering measurements directly. A satisfactory agreement in terms of penetration, asymmetric, and velocity fields is found inside the engine. Additionally, the simulation is studied on different planes the interaction between fuel spray and flow field *during* the injection, to develop a set of phenomenological models for the in-cylinder flow-spray interaction.

Furthermore, multiple consecutive motored cycles of the Darmstadt Engine are simulated using an LES approach. Good agreement with experimental data is found. The LES results are then used to analyze the turbulence production into the engine and their correlation with the Cycle-Cycle Variability (CCV). Last, due to the importance of the boundary layer in engine efficiency, a set of near-wall flow variables have been extracted and analyzed.